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EVALUATION OF THE HAZARD FROM DRY ICE CARGO

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Environmental Health Laboratory
McClellan Air Force Base, California

March 1968

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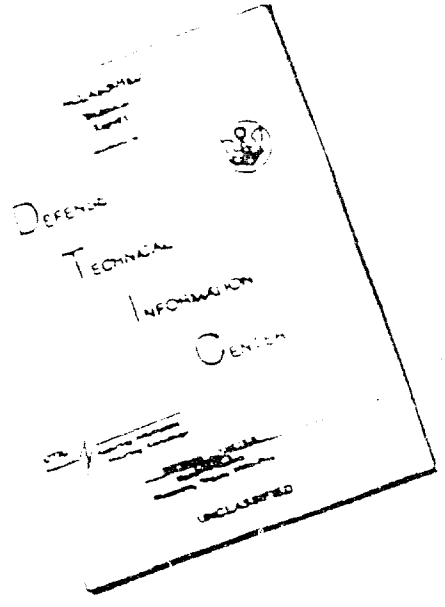

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EVALUATION OF THE HAZARD FROM DRY ICE CARGO

by

Robert T. Maykoski, Major, USAF

March 1968

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REGIONAL ENVIRONMENTAL HEALTH LABORATORY
McClellan Air Force Base, California

EVALUATION OF THE HAZARD FROM DRY ICE CARGO

Report No. 68M-10
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March 1968

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13. ABSTRACT

The health and safety implications and protective measures established by AFM 71-4 for the use of dry ice as a refrigerant in-flight were critically examined. In-flight and ground level sublimation data and resultant aircraft CO_2 levels were obtained. A mandatory precautionary ventilation procedure, which is not presently included in the existing manual, was recommended to protect passengers and crew from excessive exposure to CO_2.

II

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SECTION I

INTRODUCTION

Dry ice is used on board MAC planes as a refrigerant. Practically all shipments in MAC operations are well below load limitations specified in AFM 71-4. Dry ice packed biological shipments are typical loads, and over 95 percent of these loads are at less than one-fifth of the current restrictions. Most loads are aboard C-124 and C-130 aircraft and amount to two or three barrels (280-420 pounds). By coordination with Travis AFB, this laboratory was on call for any large shipments which might take place.

Dry ice gradually releases CO_2 at a rate, according to Pan American (Ref. 1), which in-flight is normally about 9 cubic feet per 100 pounds of dry ice per hour at altitudes or cabin pressures in the order of 8,000 feet with temperatures ranging between 60-80° F.

Studies by previous investigators, Mykytka (Ref. 1) for Pan American Aviation and Person (Ref. 2) for the Air Force, are summarized in Table 1. The results indicate that under normal flight conditions the CO_2 concentrations in the cabin and cockpit were toxicologically insignificant if one accepts the criteria that the pilot's exposure should not exceed 0.5 percent CO_2 and the exposure to other crew members averages not more than 0.5 percent CO_2, with occasional peaks permitted to nc more than 2 percent. The basis for these criteria and toxicological background material are presented in Appendix I. Appendix II includes some additional valuable summary data on carbon dioxide physiological effects for ready reference. The CO_2 concentration attained in grounded aircraft is significant, as will be shown, even when dry ice loads meet weight limitations.

SECTION II

EXPERIMENTAL DETAILS

In-flight CO_2 testing was performed aboard C-130, C135, and CL-44 (2 flights) aircraft with loads below weight limitations specified in AFM 71-4. Carbon Dioxide levels were measured throughout the aircraft at approximately 15 minute intervals. The measuring devices used were the Dwyer CO_2 Indicator, 0-5 percent range (Model 800-5), Dwyer Manufacturing Company, or the Mine Safety Appliances Company CO_2 Detector

Tubes, 0.05-5.0 percent range, part No. 85976, and the MSA Universal Pump. Appropriate corrections were made for altitude, and the instrumentation was calibrated with standard gas mixtures.

Static or ground-level testing was performed aboard the C-124 (two tests), C-130, and C-135 aircraft. Carbon dioxide levels were measured throughout the aircraft at more frequent intervals (approximately every seven minutes) than the in-flight tests, and the same instrumentation and calibration procedures were used as indicated above on in-flight testing.

Laboratory testing was performed on typical load configurations to determine the sublimation rate by measuring net weight losses under ambient conditions.

SECTION III

RESULTS AND SUMMARY

Interviewing military and civilian groups for experiences with dry ice, especially possible massive overexposures, has revealed the reporting of only a few incidents. The file on aircraft incidents at the Norton IG group failed to indicate any problem. Interviewing air crews brought to light several episodes, but the air crew members appear reluctant to report them officially. (One pilot, who had to put his crew on 100 percent oxygen in a C-135 carrying 2000 pounds of dry ice, states, "If I reported the difficulty we had, they would say I'm a heck of a pilot to fly with a dangerous load, but who am I to refuse the load? I'm no toxicologist. For all I know, maybe the cause of my symptoms was some bad orange juice I had the night before.") One documented case was a contract airlines CL-44 flying out of Tachikawa Air Base, Japan, with 2000 pounds of dry ice on frozen dinners in ordinary cardboard boxes. The aircraft was closed up for 4-5 hours after loading, and apparently one or more members of the crew were overcome prior to takeoff. MAC officially reported another incident with a C-135 loaded with 33 passengers and 41 packages of frozen dinners. Some difficulty in breathing among passengers was observed prior to flight time, so a portion of the dinners was downloaded. No dry ice weight was reported, but a reasonable estimate would be about 400 pounds.

The major studies performed to date on the CO_2 build-up in grounded aircraft indicated that there is an excessive concentration of CO_2 in the cabin breathing zone and at the floor level. In the March 1957 test performed by Person (Ref. 2) on a C-118 with a load of half the permissible amount of dry ice, the following cabin CO_2 concentrations

were observed after 1 1/2 hours:

Floor, Aft, 11.0 percent
Breathing Zone, Aft 2.5 percent
Breathing Zone, Forward 2.0 percent
Breathing Zone, Crew Compartment 0.2 percent

Other tests performed by Person (Ref. 2) and Mykytka (Ref. 1) show cabin breathing zone levels above 0.5 percent and ranging up to 3.4 percent, even with the aircraft doors open.

Tests performed by this laboratory on grounded aircraft are summarized in Table II and confirm the fact that weights below load limits will cause significant amounts (above 0.5 percent) of CO_2 to accumulate in as little as one hour. Of interest for waiting times of more than one hour is the C-135 study performed by this laboratory in March 1964 (Static Test No. 2, Appendix III) which resulted in relatively steady build-up of CO_2 with a 450 pound dry ice load to breathing zone levels above 2 percent in three hours and above 3 percent in four hours with the cargo and access doors closed. These results show that the CO_2 problem is intensified with pressurized aircraft in a "buttoned-up" condition.

Tables II and III summarize data obtained by this laboratory on ground and in-flight tests respectively, while Appendixes III, IV, and V contain the raw data on static, in-flight, and laboratory tests respectively.

AFM 71-4, as revised (15 November 1965), partially recognizes the problem of CO_2 build-up in pressurized aircraft by specifying that when a pressurized aircraft is on "minimum" air changes per hour, safe loads are to be drastically reduced. Dry ice may not be loaded above specified quantities when certain pressurized aircraft will be on the ground longer than 45 minutes. This limitation does not preclude the possibility of trouble arising from the situation where normal AFM 71-4 load limitations are maintained, and the aircraft is unavoidably delayed for times exceeding 45 minutes. Restrictive limits, other than original load limits, are not given in AFM 71-4 for non-pressurized aircraft. The experience of Person (Ref. 2) and the data obtained by this laboratory, (Table II), indicate that significant quantities of CO_2 can accumulate in one hour and that the natural ventilation rate of grounded aircraft may be less than one to two air changes per hour (see graphs in Appendix III). This ventilation rate is variable even with all doors and hatches open, and the sublimation rate of dry ice under different packaging modes is also quite variable. Sublimation rates have been shown to vary from 1.1 to 3.96 lbs/100 lbs dry ice/hr in aircraft static test and laboratory tests performed (Appendices III and V).

Based on the above discussion, the authors recommend an arbitrary mandatory procedure be employed which requires the use of the MAI Model G2 ground powered air-conditioning unit to provide dilution ventilation if the waiting time on the ground (for any aircraft carrying dry ice) exceeds 45 minutes. The MAI Model G2 units are designed to deliver 1800 cubic feet of refrigerated air per minute to the cabin of the aircraft. This capacity is sufficient to provide adequate dilution ventilation for anticipated loadings.

The load restrictions and the maintaining of open cargo and access doors during and after the loading of dry ice and cargo until takeoff time as required in AFM 71-4 must also be enforced.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

A. Present load restrictions for dry ice, as indicated in AFM 71-4, apparently create no problem in Air Force in-flight conditions if there is not an excessive concentration of CO_2 prior to takeoff. Most Air Force loads do not approach load restriction levels.

B. The few reported cases of CO_2 incidents from dry ice in aircraft appear to have resulted from a buildup of CO_2 levels in the cabin prior to takeoff, and symptoms became manifest either on the ground or shortly after takeoff.

C. Tests (Table I and II) have shown that the cabin CO_2 breathing zone concentrations with dry ice loads at or below AFM 71-4 restriction levels readily reach 1 percent in one hour, with much higher concentrations present at floor level during ground operations.

D. If the time exceeds 45 minutes on the ground for aircraft carrying CO_2, the provision of adequate mechanical exhaust ventilation should be made mandatory through the use of ground powered air-conditioning units such as the MAI Model G2.

SECTION V

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TABLE I

REPORTED CO_2 TESTS

In-Flight	Dry-Ice Loading	Container	Test Location	Ventilation	Sublimation Rate Lbs/ 100 lbs/hr	%CO_2 in Crew Compart-ment	%CO_2 in Cabin Breath Zone	%CO_2 at Floor	Tes Age
Sept 46 DC-3	2000 lbs	Fiberglass	Cabin	Closed Cabin vents	1.1	Negl.	NR*	4.0	PA/
Mar 57 C-118	1500 lbs	None	Cabin	Normal no vent	NR	0.4-0.8	0.2-2.0	2.0-4.4	USA
Mar 57 C-124	2000 lbs	None	Cabin	Normal	NR	NR	0.0-0.6	0.0-3.4	USA
Mar 57 C-54	1500 lbs	None	Cabin	Normal	NR	NR	0.0-0.2	1%	USA
Mar 57 C-121	2000 lbs	None	Cabin	Normal	NR	NR	0.0-1.0	0.0	USA
				Depres-surized	NR	0.0	0 0-0.2	0.2-6.0	
Nov 58 DC-4	500 lbs	None	Belly Cargo	NR	NR	0.0	0.3	NR	PA/
During 61 DC-7G	1800 lbs	Not specified (crushed ice)	NR	Normal		0.08	0.2-0.4	NR	PA/
				1 blower	0.99	0.17	0.4-0.6	NR	PA/
Jan 63 DC 7CF	5000 lbs	Cardboard	Cabin w/ sealed Bulkhead	Normal	1.1	0.0-0.2	0.5-1.6	NR	PA/
				Raw air	1.1	0.3-0.5	0.4-1.5	NR	PA/
				Crew air only	1.1	0.1-0.5	0.6-2.4	NR	PA/
				Descent	1.1	0.2-0.3	2.2-2.8	NR	PA/
				Taxi	1.1	0.2	3.4	NR	PA/
May 63 C-135B	800 lbs	Paper	Baggage	Normal	NR	.26	.1-.33	NR	USA

* NR - Not Reported

TABLE I (CONT'D)

REPORTED CO_2 TESTS

On Ground	Dry Ice Loading	Container	Test Location	Ventilation	Sublimation Rate Lbs/ 100 lbs/hr	%CO_2 in Crew Compartment	%CO_2 in Cabin Breath Zone	%CO_2 at Floor	Test Agenc
Mar 57 C-118	500 lbs	None	Cabin	Normal	2.7-4.75	0.2-1.2	0.2-7.0	7.4-11.4	USAI
Mar 57 C-124	2550 lbs	None	Cabin	Drs Closed Drs Open	NR NR	0.4 NR	0.8-2.4 0.5-1.4	7 NR	USAI USAI
Mar 57 C-54	1500 lbs	None	Cabin	Drs open Drs Closed	NR NR	0.0 NR	0.0-0.2 0.0-0.5	2.2-2.8 1.0	USAI
Mar 57 C-121	2225 lbs	None	Cabin	Drs Open Fans On	NR NR	NR NR	0.0-3.4 NR	8.4 0.2	USAI
Jan 63 DC-7CF	5000 lbs	Cardboard	Sealed Cargo Comp	One Super-charger	1.12	NR	0.5-1.4	1.0-2.0	PAA

TABLE II

GROUND TESTS - DRY ICE IN AIRCRAFT

Aircraft	Dry Ice Loading Wt. in pounds	Container	Sublimation Rate Lbs CO_2/100 lbs dry ice/hr	Cabin % CO_2 at 1 hr 3-4 ft. ht.	Cabin Max % 1-4 ft.
Mar 64 C-124	1065	Paper wrapped covered with blankets	1.32	0.80	1.10
Mar 64 C-135	450	Paper wrapped covered with blankets	3.96	0.85	3.2
Apr 64 C-124	1600	Paper wrapped covered with blankets	1.60	0.20	0.90
Jul 64 C-130	2282	Paper wrapped covered with blankets	2.02	0.40	1.50

TABLE III

IN-FLIGHT, DRY ICE TESTS

Aircraft	Dry Ice Loading Wt. in Pounds	Container	Cabin $\%CO_2$ 3-4 ft. ht. at 1 hr.
C-135	1490	16 Barrels	1.10 (at time of taxi)
CL 44	200	Cardboard (opened occasionally)	0.20
CL 44	2500	Cardboard Boxes	0.18
C-130	945	7 Barrels	0.25

APPENDIX I

CARBON DIOXIDE TOXICOLOGY

Unlike most chemical contaminants which are alien to man's bio-environment, carbon dioxide is both a normal constituent of the atmosphere and also a natural excretory product of the body's metabolism. The normal concentration of carbon dioxide in the air is about 0.03 percent (300 ppm) although in heavy industrial cities it may range from 400 to 700 ppm. Under severe air pollution conditions brought about by temperature inversions it has been measured at concentrations up to 0.1 percent (1000 ppm). At altitudes from 3300 to 10,000 feet, Bischof (Reference 2) found the concentration was much more constant than at ground level, varying from 308 to 320 ppm with an average of 314 ppm.

Man's normal respiratory exchange excretes carbon dioxide to the atmosphere. Normal partial pressures and percent concentrations are shown in Table I. As shown in the various columns, the atmospheric air is first humidified in the airways, then at the alveoli the transport of oxygen into the blood and carbon dioxide from the blood to the air occurs. Finally, the air is expired together with a large amount of air in the airways that was in the "dead" portion of the airways and not involved in the gas exchange process. The data for expired air thus is a combination of the alveolar air and humidified air.

The toxicology of carbon dioxide by inhalation chiefly concerns increased ventilatory response plus its asphyxia effect at very high concentrations. Carbon dioxide is the major chemical factor regulating alveolar ventilation, and its stimulation of the respiratory center provides a very important feedback mechanism for the regulation of the concentration of carbon dioxide throughout the body. Initially, the inhalation of increased concentrations of carbon dioxide at sea level increases the depth of breathing and thus the tidal volume is increased. This increasing respiration becomes noticeable at 2 percent (20,000 ppm) and by 3 percent increases respiration by 90 percent. Symptoms are quite marked at 4 percent, becoming labored at 4.5 percent and showing an alveolar ventilating increase of 350 percent over basal. By 10.6 percent CO_2, a peak increase of 1200 percent in ventilation has been found. Smyth quotes from Flury and Zernik to the effect that 5500 ppm (0.55 percent) causes no noticeable symptoms in six hours (Ref. 11).

Ulvedal, Cutler and Welch (Ref. 12), in a series of tests which included some at 0.4 and 3 percent CO_2 at 700 MM Hg for four days, did not report any respiratory distress but showed slightly increased urinary excretion of epinephrine, norepinephrine, and corticosterone-like hormones.

Schaefer (Ref. 10), in exposures of 39 males to 3.5, 5.4, and 7.5 percent CO_2 in air for 15 minutes, showed the increase in respiratory minute volume with increasing CO_2 concentrations. No significant discomfort was reported at the lower two, but at 7.5 percent, six noted dizziness, four claimed loss of control of limbs, seven complained of loss of balance, ten had visual difficulties, and two were mentally disoriented.

Consolazio et al (Ref. 5) exposed two groups of 37 and 77 men to gradually increasing CO_2 concentrations of up to 5.27 and 5.18 percent respectively. Duration of exposure was 60 and 50 hours, with 26 and 16 hours at the maximum concentration. No significant mental deterioration was reported but physiological effects including nausea and headache were apparent at 5 percent.

Brown (Ref. 3), in a study of 11 men exposed to an increasing CO_2 percentage up to 5.8 percent in eight hours, noticed marked increase in physiological effects at between 4.7 and 5.2 percent. Using Army alpha cancellation and addition tests at gradually increasing concentrations up to 5.8 percent for 8 and 12 hours exposures, he observed that between 5.5 and 6.0 percent the efficiency curve fell off rapidly. He also exposed three subjects at 6.0 percent CO_2 and 21.1 percent oxygen for 20 minutes, reporting much discomfort, though not intolerable.

Of six subjects exposed to 7.5 percent CO_2 and 16 percent oxygen from 3.5 to 6 minutes, he reported discomfort, but again did not consider this at the limit of tolerance.

White (Ref. 14) exposed 31 males (20 of whom were physicians) to 6.0 percent CO_2 in air and in oxygen for 16 minutes at an equivalent altitude of 5,000 feet. One subject failed to complete the tests, reporting dizziness and marked dyspnea. All reported dyspnea, five believed it to be severe; the remainder reported the difficulty of breathing to be slight or moderate. Mean respiratory volume rose from 12/1 minute to about 38 l/minute for CO_2 in air and 30 l/min for CO_2 in oxygen. Headache was a common symptom; one subject reported the headache severe. Two subjects reported subjective difficulty with vision. Other common subjective sensations were: a feeling of fatigue; fogginess; more concentration was required during a card sorting test. The errors and speed of card sorting were not influenced, however. Of the 26 subjects breathing CO_2 in air, 18 believed the CO_2 would not influence driving or piloting at all, six felt their performance was not up to par, and two did not report.

Dripps and Comroe (Ref. 6) exposed 42 subjects to 7.6 percent CO_2 in oxygen for a sufficient time to obtain a plateau in the MRV (minute respiratory volume). It did so in only 27 of 42 individuals at times from 2.5 to 8.5 minutes. The others were discontinued when discomfort ensued. Unconsciousness occurred in one subject, dyspnea was reported in 13, and dizziness in nine subjects during the exposure, and five after inhalation of CO_2. He further studied 31 subjects exposed to 10.4 percent

CO_2 in oxygen for from 2.5 to 6 minutes. All were in a stuporous "glassy-eyed" state after exposure, and three subjects collapsed.

Further work by Consolazio et al (Ref 5) at 5 percent and Gelhorn and Kraines at 6 to 7 percent CO_2 afforded a potent argument for staying below concentrations of 6 to 7 percent. In Brown's study at concentrations containing 12.4 percent CO_2 and 39.7 percent O_2, one of seven subjects collapsed in 45 seconds and other exposures were terminated after 45 seconds to 2 minutes. All of the latter felt that they would lose consciousness in a few more minutes. A dazed condition persisted for several minutes after exposure was terminated.

Spealman (pp 53-54, Ref. 1) tested three subjects at 27.9 percent CO_2 and 15.0 percent O_2 for a half minute and 17.0 percent CO_2 and 17.3 percent O_2 for 3/4 minute. Irritation of the throat, increased respiration, dimness of vision, and a feeling of impending unconsciousness were noted in all cases. All subjects were essentially helpless at conclusion of exposure.

Hill and Flack's (Ref. 8) study of exposures to mixtures of 64.6 percent CO_2 and 8.6 percent O_2 and then 38 percent CO_2 and 9 percent O_2 showed spasm of the glottis and immediate inhibition of respiration, whereas 20 percent CO_2 produced immediate partial spasm of the glottis, causing a peculiar whooping sound during inspiration.

All of the above data was summarized in a time-concentration curve by White, which is illustrated in Figure 1 (from Ref. 1). Effect of altitude upon the ventilation response increase is a function of the partial pressure of the carbon dioxide (pCO_2) that is present in the alveoli. White, in his study of significance of high concentrations of CO_2 in aviation medicine, prepared a table and graph providing the equivalent dry percentage of CO_2 in a gas at altitude which will give the same partial pressure (calculated wet) as does a dry percentage of CO_2 at sea level (Table II). As an example, 5 percent CO_2 (dry) at sea level represents a pCO_2 at 15,000 feet, the dry CO_2 concentration must be between 9 and 10 percent. This was shown experimentally to be true by Weatherby and Burt in a study on 15 subjects inspiring 5 percent CO_2 at sea level with an increase in average ventilation of 225 percent. Yet at 15,000 feet it required 9.25 percent CO_2 for the same effect. Thus, higher percentages of inspired CO_2 can be inhaled at altitude before "loading" of CO_2 into the blood occurs than is the case at sea level.

CRITERIA

The American Conference of Governmental Industrial Hygienests have established a threshold limit value for carbon dioxide of 5,000 ppm (0.5 percent) for an eight hours per day, five days per week exposure lasting a working lifetime. This value is a time-weighted average concentration which recognizes that said value will be exceeded for short periods. The amount by which it is exceeded depends upon factors such as ability to produce acute poisoning, whether effects are cumulative, how often such high concentrations occur, and the duration of such periods. Experience since its adoption in 1943 has shown that this value is low enough to prevent noticeable effects.

The Civil Aeronautics Administration (now the Federal Aviation Agency) in 1948 issued a policy statement regarding 3 percent CO_2 at standard atmosphere as dangerous and suggested that closed system emergency respiratory gear covering the eyes, nose, and mouth be required for crew members serving in aircraft which under any circumstances may exceed the 3 percent CO_2 figure (21-22 mm) in the cockpit. In December 1963 the Federal Aviation Agency published an Advisory Circular, stating the CO_2 average concentration in the aircraft generally should not be allowed to exceed 0.5 percent (5,000 ppm), stating that it was the intent to make the value consistent with the Maximum Allowable Concentration in industrial exposures.

Pan American, in their study (Ref. 9), used a limit of 0.5 percent CO_2 in the cockpit and a normal aircraft operation exposure of 0.5 percent in the cabin air, three feet from the floor. Intermittent exposures of up to 4 percent were tolerated, but for cargo aircraft cabins, a limit of 2 percent was set.

Space capsule environments present a peculiar problem regarding CO_2 due to the human being the prime source of this contamination. Welch (Ref. 13A) stated at the 1962 lectures in Aviation Medicine that the CO_2 should not exceed 7 to 8 mm Hg pCO_2 sea level equivalent (1 percent). Burke et al of Vought Aeronautics, in their published report for the Air Force (Ref. 4), stated that the tolerance limits should be maintained at less than 15 mm Hg pCO_2 which corresponds to 2 percent at sea level. The optimum was quoted at the ambient air level of 0.3 mm Hg pCO_2 (0.03 percent).

A satisfactory criteria would appear to be that the pilot's exposure does not exceed 0.5 percent CO_2 and the exposure to other crew members not more than 0.5 percent CO_2, with occasional peaks permitted of not more than 2 percent.

TABLE I

PARTIAL PRESSURES AND PERCENT CONCENTRATION OF RESPIRATORY GASES

AS THEY ENTER AND LEAVE THE LUNGS

Component	Atmospheric Air		Humidified Air		Alveolar Air		Expired Air	
	mm Hg	% Conc.	mm Hg	% Conc	mm Hg	% Conc	mm Hg	% Conc
N_2	597.0	78.62	563.4	74.09	569.0	74.9	566.0	74.5
O_2	159.0	20.84	149.3	19.67	104.0	13.6	120.0	15.7
CO_2	0.3	0.04	0.3	0.04	40.0	5.3	27.0	3.6
H_2O	3.7	0.5	47.0	6.2	47.0	6.2	47.0	6.2
Total	760.0	100.0	760.0	100.0	760.0	100.0	760.0	100.0

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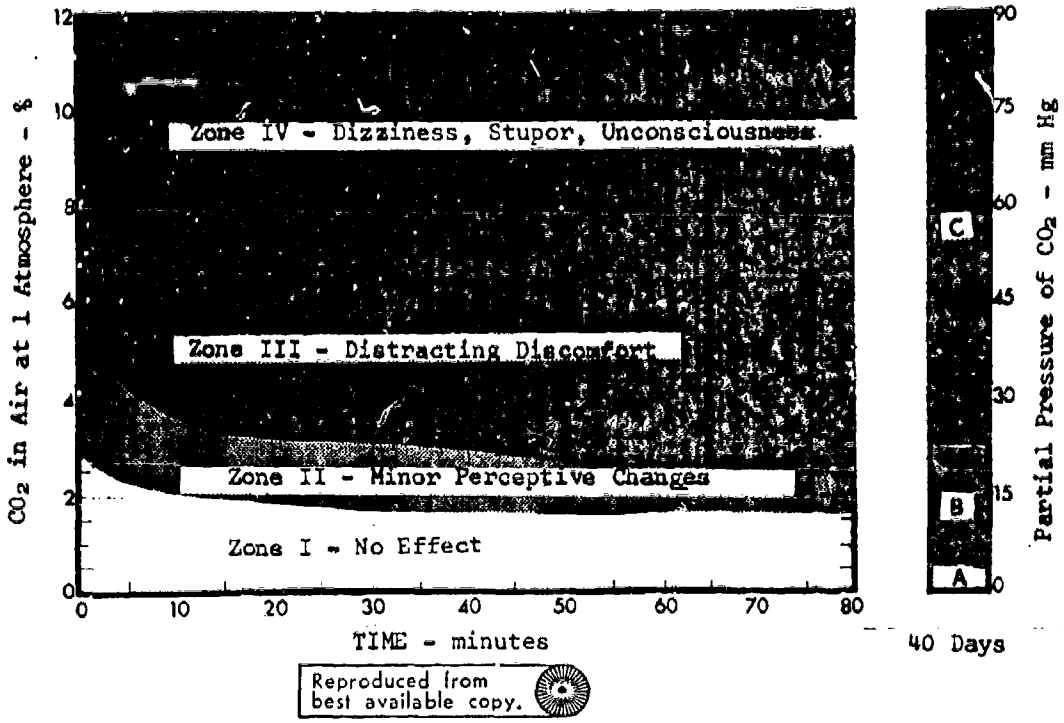
APPENDIX II

CARBON DIOXIDE EFFECTS



The chart taken from Bioastrorantic Data Book, NASA SP-3006 shows the general symptoms common to most subjects when exposed for the times indicated to mixtures of carbon dioxide in air at a total pressure of 1 atmosphere. In Zone 1, no psychophysiological performance degradation, or any other consistent effect, is noted. In Zone II, small threshold hearing losses have been found and there is a perceptible doubling in depth of respiration. In Zone III, the zone of distracting discomfort, the symptoms are mental depression, headache, dizziness, nausea, "air hunger," and decrease in visual discrimination. Zone IV represents marked deterioration leading to dizziness and stupor, with inability to atke steps for self-preservation. The final state is unconsciousness.

The bar graph at the right shows that for prolonged exposures of 40 days, concentrations of CO_2 in air of less than 0.5% (Zone A) cause no biochemical or other effects; concentrations between 0.5 and 3.0% (Zone B) cause adaptive biochemical changes, which may be considered a mild physiological strain; and concentrations above 3.0% (Zone C) cause pathological changes in basic physiological functions.

REFERENCES

1. King, B.G., "High Concentration - Short Time Exposures and Toxicity," JAIHA (1949), 31, pp 365-375.

2. Nevison, T.O., Jr., Letter report to the Garrett Corp. The Lovelace Foundation, Albuquerque, New Mexico, January 25, 1962.

3. Schaefer, K.E., "A concept of Triple Tolerance Limits Based on Chronic Carbon Dioxide Toxicity Studies," Aerospace Medicine (1961), 32, pp 197-204.

APPENDIX III

GROUND TEST DATA
TESTS 1-4

A. GROUND TEST NO. 1 (C-124, 1065 lb. load, Travis AFB, 24 March 1964)

1. Aircraft Data: C-124 with no additional cargo aboard. All hatches and doors were kept closed except for crew access door in front of plane.

2. Dry Ice Data: 1065 pounds of dry ice were taken in the form of about 30 brown paper wrapped packages. They were wrapped for additional insulation in eight G. I. wool O. D. blankets. This made a pallet load 3 feet high and 2 1/2 x 3 feet at base tapering somewhat toward the top.

Gross weight at 1045 hours	1150 lbs
Blankets and pallet	85
Net weight of dry ice	1065 lbs
Gross weight at 1500 hours	1085 lbs
Blankets and pallet	85
Net weight of dry ice	1000 lbs

Average dry ice load $\frac{(1065 + 1000)}{2}$ = 1033 lbs

3. Sublimation Rate: $\frac{1065 - 1000}{1033/100 \text{ (1500-1045 hours)}} = \frac{65}{10.33 \times 4.75}$ = 1.32 lbs/100 lb-hour

4.75 hour

Air temperature: 16-18°C

Table I and Figure I summarize and illustrate test results.

4. Carbon Dioxide Concentration Data - Source: 1065 pounds of dry ice with sublimation rate of 1.32 pounds per 100 pounds per hour in closed off C-124 aircraft with source located at stations 825 to 870.

5. Instrumentation: Carbon Dioxide Indicator, 0-5 percent range, Serial No. 1 (Dwyer Manufacturing Company Model No. 800-5).

B. GROUND TEST NO. 2 (C-135-450 lb. load, Travis AFB, 31 March 1964)

1. Aircraft Data: C-135, Serial 61-2663, in cargo configuration with no other cargo aboard. All hatches and doors were closed except for occasional opening of the crew access door in the crew compartment.

2. Dry Ice Data: 450 pounds of dry ice were taken in the form of nine brown paper wrapped 50 pound packages, and wrapped for additional insulation, in eight G. I. wool O. D. blankets. This made a package 2 feet high and 2 1/2 feet x 1 foot at base. Weights were taken before and after loading and at about one mile from aircraft.

Gross weight at 0935 hours	550 lbs
Blankets and pallet	100 lbs
Net weight of dry ice	450 lbs
Gross weight at 1450 hours	465 lbs
Blankets and pallet	100 lbs
Net weight of dry ice	365

$$\text{Average dry ice weight} = \frac{450 + 365}{2} = 408 \text{ lbs.}$$

3. Sublimation Rate:

$$\frac{(450 - 365)}{408/100 \text{ lbs } (1450 - 0935)}$$

5.25 hour

$$\frac{85 \text{ lbs}}{4.08 \times 5.25} = 3.96 \text{ lbs/100 lb-hour}$$

Air Temperature 16° to 18° C
Table and Figure II summarize and illustrate test results.

4. Carbon Dioxide Concentration Data - Source: 450 pounds of dry ice with sublimation rate of 3.96 pounds per 100 pounds per hour in closed off C-135 cargo aircraft with source located at Station 1140 (aft end of aircraft).

5. Instrumentation: Carbon Dioxide Indicator, (FSN 6665-098-5805) 0-5 percent Serial No. 1, Dwyer Manufacturing Company, (Model 800-5) calibrated with Alveolar air (4.8percent CO_2) before and during test.

C. GROUND TEST NO. 3 (C-124-1600 lb load, Travis AFB, 22 April 1964)

1. Aircraft Data: C-124 with no additional cargo aboard. All hatches and doors kept open.

2. Dry Ice Data:

Net weight of dry ice at 0930 hours	1600 lbs.
Net weight of dry ice at 1437 hours	1470 lbs.
Loss was 130 pounds in 5.1 hours $\cong$	$\frac{130 \times 100}{5.1 \times 1535}$
1.6 lb/100 lb-hour	

Table III summarizes test results.

D. GROUND TEST NO. 4 (C-130, 2282 lb load, Travis AFB, 21 July 1964)

1. Aircraft Data: Cargo aircraft, C-130, Serial 57-787, with no other cargo on board was used for this test. The crew access door in the nose was open throughout the test as were the windows in the pilot's compartment. Left side door in the cargo compartment was open for 1 1/4 hours; then the door was closed for the remainder of the test.

2. Dry Ice Data: A total of 2282 pounds of dry ice in the form of about 70 brown paper wrapped packages were placed on three pallets and wrapped for additional insulation in six GI wool blankets each. Weights were taken on board the aircraft before and after the test, and one pallet remained on the scale throughout the test to furnish sublimation rate data.

3. Sublimation rates:

Pallet No. 1

$$\frac{616 - 556}{586/100 \quad 3.92} = 2.61 \text{ lbs/100 lb-hour}$$

Pallet No. 2

$$\frac{842 - 780}{811/100 \quad 3.78} = 2.02 \text{ lbs/100 lb-hour}$$

Pallet No. 3

$$\frac{824 - 782}{803/100 \quad 3.68} = 1.42 \text{ lbs/100 lb-hour}$$

4. Instrumentation: Carbon Dioxide Indicator, FSN 6665 098 5805, 0.5 percent range, Serial No. 1, Dwyer Manufacturing Company, (Model No. 800-5) calibrated with Alveolar air (4.8 percent CO_2) before and during the test. Also, Mine Safety Appliances Company Universal Testing Kit with CO_2 tubes (P/N85976), Batch No. 5.

Table IV - VI and Figure 3 summarize and illustrate test results.

TABLE I

GROUND TEST NO. I

Time		Aircraft Station	CO_2 Conc. (%)	Sample Height (ft)
Hour	After Test Start (minutes)			
1110	0.00	N.A.	N.A.	N.A.
1130	20	660	0.30	4
1137	27	940	0.20	4
1142	32	790	0.60	4
1148	38	790	0.80	4
1156	46	810 next to pallet	3.80	floor
1203	53	810	0.80	4
1305	115	790	0.50	4
1310	120	930	1.10	4
1313	123	1090 middle bunk	0.60	4
1317	127	1090 lower bunk	0.80	2
1321	131	800	0.40	2
1324	134	790	0.10	4
1330	140	790	0.55	4
1340	150	630	0.45	4
1342	152	840 compartment below floor	1.10	5
1350	160	790	0.50	1

TABLE I CONT'D

GROUND TEST NO. 1

Time		Aircraft Station	CO_2 Conc. (%)	Sample Height (ft)
Hour	After Test Start (minutes)			
1400	170	crew compart.	0.06	4
1410	180	790	0.35	4
1416	186	930	0.35	2
1422	192	920 compartment below floor	0.30	4
1430	200	1100 middle bunk	0.40	4 1/2
1434	204	1100 top bunk	0.20	6 1/2
1436	206	1100 middle bunk	0.30	4
1440	210	1100 bottom bunk	0.35	1 1/2

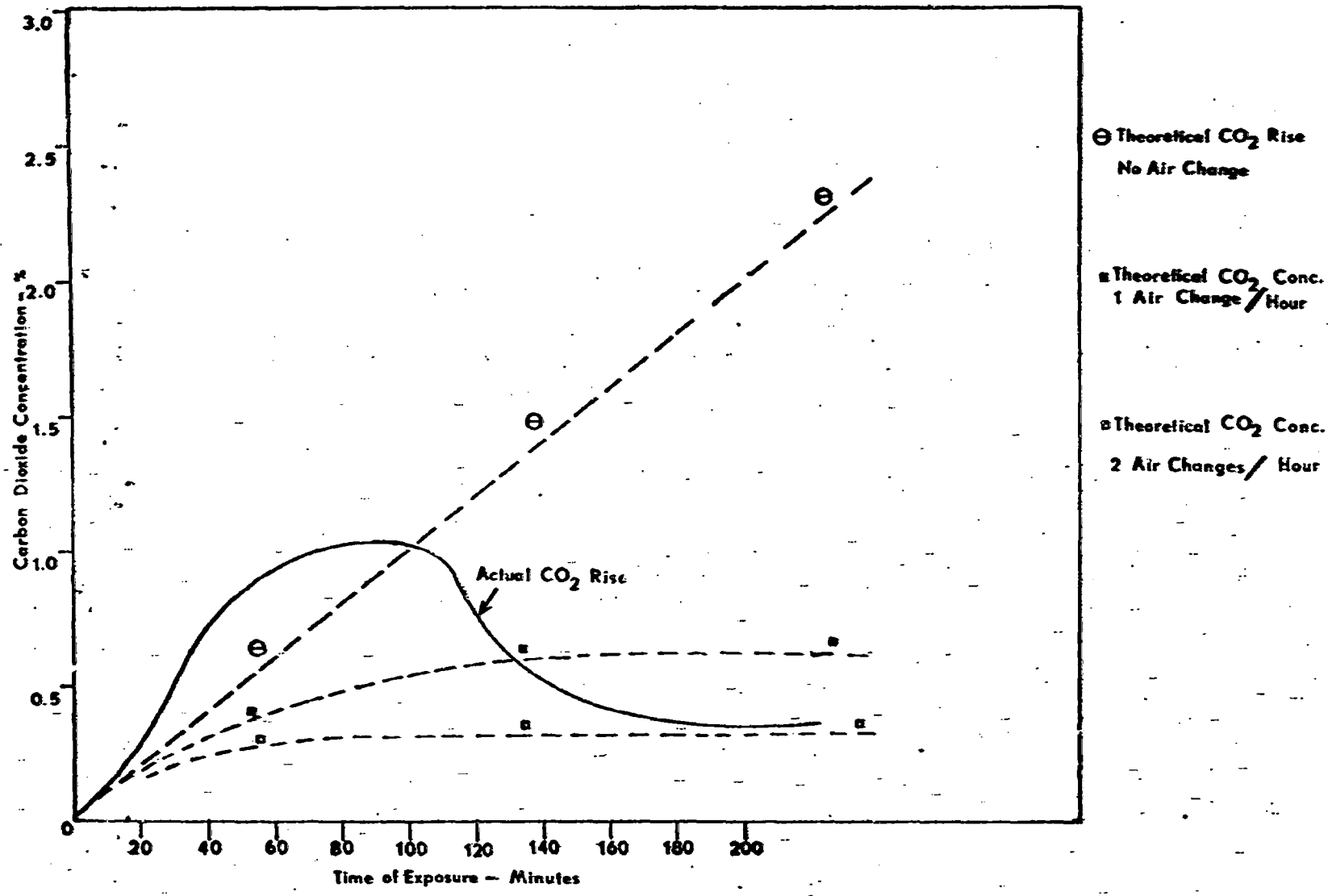


Figure 8 GROUND TEST No.1 DRY ICE PROJECT

TABLE II

GROUND TEST NO. 2

Time		Aircraft Station	CO_2 Conc%	Sample Height (ft)
Hour	After Test Start (Minutes)			
0950	0.00			
0955	5	1200	0.25	4
1000	10	1200	0.20	4
1005	15	1200	0.30	4
1012	22	1200	0.35	4
1015	25	1200	0.40	2
1020	30	1280 by inflight ovens	0.75	4
1025	35	900	0.15	4
1032	42	1200	0.45	4
1043	53	1200	0.60	4
1050	60	1200	0.85	4
1100	70	1200	1.00	4
1105	75	1200	1.10	2
1110	80	1280 by inflight ovens	1.00	4
1115	85	900	1.50	4
1117	87	600	1.20	4
1122	92	crew comp.	1.10	3
1128	98	500	1.60	6

TABLE II CONT'D

GROUND TEST NO. 2

Time		Aircraft Station	CO_2 %	Sample Height (ft)
Hour	After Test Start (Minutes)			
1130	100	500	1.60	3
1132	102	500	2.30	0.5
1136	106	900	1.50	3
1140	110	1200	1.40	4
1141	111	1200	1.60	1
1145	115	1200	1.50	6
1148	118	1280	1.40	5
1149	119	1200 right side	1.70	4
1154	124	1000	1.60	3
1202	132	700	1.60	4
1204	134	700	1.75	1
1206	136	700	1.60	6
1209	139	crew comp	1.75	4
1245	175	1000	2.20	4
1248	178	1280 by inflight oven	2.30	4
1250	180	1200	2.20	4
1320	210	1200	2.40	4

TABLE II CONT'D

GROUND TEST NO. 2

Time		Aircraft Station	CO_2 Conc. %	Sample Height (ft)
Hour	After Test Starts (Minutes)			
1334	224	1200	2.70	4
1336	226	1280	2.70	4
1338	228	1130	3.00	4
1340	230	1130	3.10	1
1343	233	1000	3.10	4
1345	235	900	3.10	4
1347	237	610	2.80	4
1351	241	crew comp.	2.50	4
1355	245	1200	2.90	4
1415	265	1200	2.90	4
1430	280	1200	3.20	4

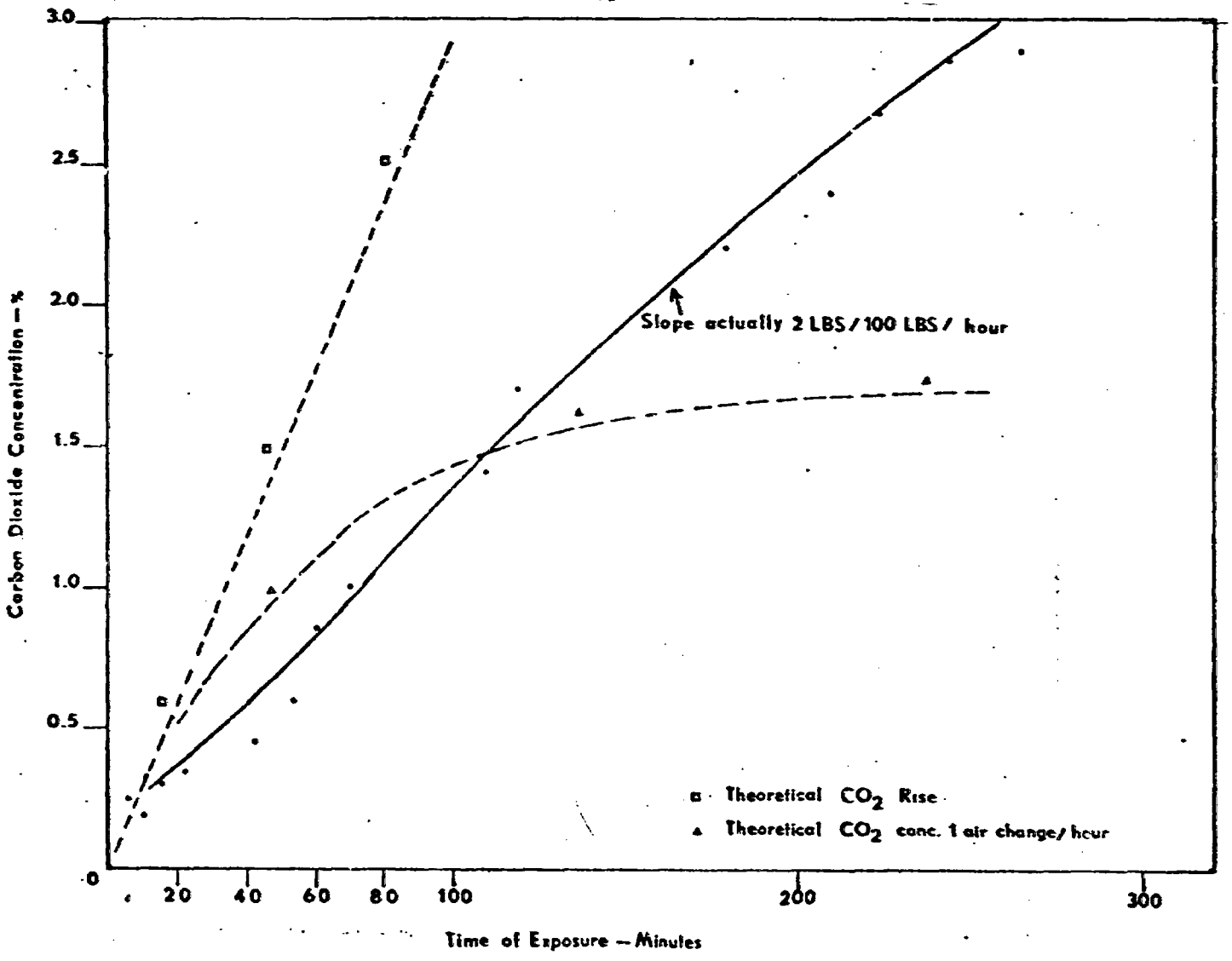


Figure 2 GROUND TEST No. 2 DRY ICE PROJECT

TABLE III

GROUND TEST NO. 3
1600 lbs Positioned on 2 Pallets
800 to 900

Time	Aircraft Station	CO_2 Conc. %	Sample Height (feet)
1000	960 R	0.30	4
1023	720 L	0.50	4
1029	960 L	0.10	4
1032	960 L	0.30	4
1044	960 L	0.50	4
1050	1100 R	0.10	1.5
1053	1100 R	0.30	1.5
1054	1100 R	0.20	1.5
1055	1100 R	0.30	4
1101	930	0.20	3.5
1103	940	0.00	4
1107	940	0.20	4
1110	940	0.45	1.5
1114	elevator well	2.30	
1118	940	0.90	1.5
1122	940	0.50	1.5
1125	940	0.60	1.5
1118	crew comp. pilot	0.15	4

TABLE III CONT'D

GROUND STATIC TEST NO. 3

Time	Aircraft Station	CO_2 Conc. %	Sample Height (feet)
1120	crew comp.	0.17	4
1123	radio navigator	0.18	4
1145	920	0.30	4
1147	920 L	0.35	2
1217	not reported	0.35	2
1220	not reported	0.30	4
1221	940 R	0.20	2
1223	940 R	0.20	4
1227	940 R	0.30	3
1230	710 L	0.10	3
1232	520 L	0.20	3
1250	520	0.30	3
1257	940	0.30	3
1349	940	0.30	3
1402	540	0.20	3
1407	lowered load from airplane		
1425	Forklift arrived		
1437	Forklift to scale		

TABLE IV

GROUND TEST NO. 4
DRY ICE SUBLIMATION DATA

	Time	Gross Weight lbs	Pallet & Blankets	Net Wt. lbs	Time	Gross Weight lbs	Pallet & Blankets	Net Wt. lbs	Δ T*	Δ W**
Pallet #1	1510	691	75	616	1905	634	78	556	3.92	60
Pallet #2	1513	925	83	842	1900	866	86	780	3.78	62
Pallet #3	1515	923	99	824	1856	884	102	782	3.68	42
		2539	257	2282		2384	266	2118	3.80	164

TABLE V

RATE OF SUBLIMATION - PALLET NO. 3

Time	Δ T*	Gross Weight lbs	Pallets & Blankets	Net Weight lbs
1515		923	99	824
1545	0.50	918	99	819
1624	1.15	912	100	812
1650	1.58	908	100	808
1720	2.08	900	101	799
1800	2.75	894	101	793
1833	3.30	890	102	788
1856	3.68	884	102	782

* Δ T = time expired in hours
** Δ W = weight difference in pounds

TABLE VI

GROUND TEST NO. 4

Time		Aircraft Station	CO_2 Conc. %	Sample Height (feet)	Instrument
Hour	Minutes				
1515	--	--	--	--	--
1525	10	670 R	0.50	2	Dwyer
1528	12	670 R	0.60	2	MSA
1528	12	670 R	0.50	2	Dwyer
1535	20	cockpit	0.10	4	MSA
1537	22	670 R	0.30	2	Dwyer
1540	25	450 R	0.30	4	MSA
1540	25	420 L	0.35	2	Dwyer
1545	30	420 L	0.35	3	Dwyer
1546	31	420 L	0.30	1	Dwyer
1545	30	850 R	0.15	3	MSA
1555	40	440 L	0.40	2	Dwyer
1558	43	680 R	0.70	1	Dwyer
1600	45	680 R	0.60	2	Dwyer
1601	46	630 L	0.40	2	MSA
1615	60	680 R	0.30	3	Dwyer
1615	60	680 R	0.40	2	Dwyer
1624	9	680 R	0.20	2	Dwyer

TABLE VI CONT'D

GROUND TEST NO. 4

Time		Aircraft Station	CO_2 Conc. %	Sample Height (feet)	Instrument
Hour	Minutes				
1630	75	680R	0.40	2	Dwyer
CLOSED LEFT SIDE DOOR - - - - - - - - - - - -					
1638	83	680R	0.50	3	Dwyer
1645	90	680R	0.70	2	Dwyer
1653	98	650L	0.15	3	MSA
1700	105	650R	0.70	3	MSA
1700	105	650R	0.60	3	Dwyer
1708	113	650R	0.70	3	Dwyer
1720	125	650R	0.90	3	Dwyer
1725	130	440L	0.60	1	Dwyer
1726	131	440L	0.40	2	Dwyer
1730	135	cockpit	0.15	4	MSA
1730	135	440R	0.30	2	Dwyer
1732	137	440R	0.30	1	Dwyer
1742	147	670R	1.40	1	Dwyer
1744	149	670R	1.50	1	Dwyer
1745	150	680R	1.40	2	Dwyer
1755	150	680R	1.20	2	Dwyer
1811	176	680R	1.20	1	Dwyer

TABLE VI CONT'D

GROUND TEST NO. 4

Time		Aircraft Station	CO_2 Conc. %	Sample Height (feet)	Instrument
Hour	Minutes				
1816	189	680R	1.40	1	Dwyer
1824	197	680R	1.40	1	Dwyer
1832	197	680R	1.00	2	MSA
1838	203	680R	0.90	2	Dwyer
1845	210	680R	0.60	3	MSA
1846	211	680R	0.90	2	Dwyer
1850	215	680R	0.90	2	Dwyer
1853	218	680R	1.30	2	Dwyer
1855	220	680R	1.30	1	Dwyer

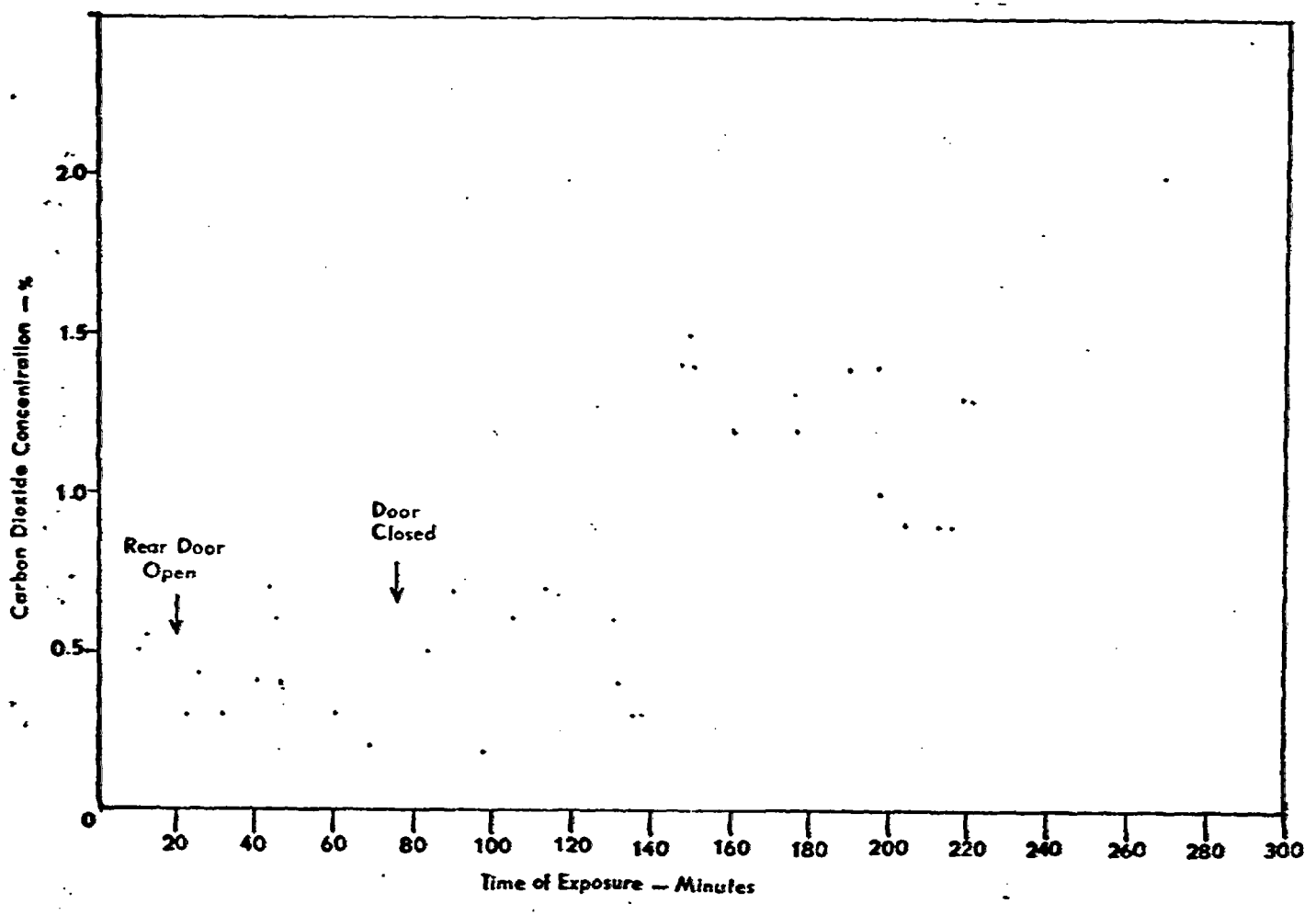


Figure 3-GROUND TEST No.4

DRY ICE PROJECT

APPENDIX IV

FLIGHT TEST DATA

A. FLIGHT TEST # I

2500 pounds of dry ice was loaded in four cardboard boxes between 1300 - 1500 hours on 31 October 1964.

Load was placed in F.T.L. CL-44 between 1500-1530 hours on 31 October 1964. Doors were closed at 1545 hours. Take off time was 1600 hours. Door between cabin and cockpit was open during flight. Cabin altitude was 3000 feet.

Dry ice was located at pallets 1 and 2.

Curtain separated all but about 2-3 foot width between cargo and seats.

Persons cannot walk past end of pallet #2. Cargo was only about 6 inches from side of aircraft.

Position #1	By engineer's chair
Position #2	2nd row of seats (from front)
Position #3	End of pallet #1
Position #4	End of pallet #2

FLIGHT TEST I

TIME	POSITION	ALTITUDE	T°C	CO_2 CONC%	SAMPLE HEIGHT (ft)	TYPE SAMPLER
1550	2	Eng. start and Taxi	20	0.30	3	MSA
1600	2	Take off	20	0.15	3	MSA
1609	2	Climb	20	0.10	3	MSA
1615	2	16,000	20	0.12	3	MSA
1630	2	16,000	18	0.18	3	MSA
1645	2	16,000	19	0.18	3	MSA
1700	1	16,000	19	0.18	3	MSA
1715	2	16,000	19	0.20	3	MSA
1730	2	16,000	19	0.21	3	MSA
1745	2	16,000	19	0.20	3	MSA
1800	3	16,000	19	0.35	3	MSA
1815	4	16,000	19	0.22	3	MSA
1830	1	16,000	19	0.20	3	MSA
1845	2	16,000	19	0.15	3	MSA
1900	2	16,000	19	0.17	3	MSA
1915	3	16,000	19	0.20	3	MSA
1930	4	16,000	19	0.28	3	MSA
1945	1	16,000	19	0.20	3	MSA
2000	2	16,000	19	0.20	3	MSA
2015	3	16,000	19	0.25	3	Dwyer
2030	4	16,000	19	0.20	3	Dwyer
2045	1	16,000	19	0.20	3	Dwyer

TABLE (cont)

TIME	POSITION	ALTITUDE	T°C	CO_2CONC%	SAMPLE HEIGHT(ft)	TYPE SAMPLE
2100	2	16,000	19	0.20	3	Dwyer
2115	3	16,000	19	0.30	3	Dwyer
2130	4	16,000	19	0.25	3	Dwyer
2145	1	16,000	19	0.20	3	Dwyer
2200	2	16,000	20	0.20	3	Dwyer
2215	3	16,000	20	0.30	3	Dwyer
2230	4	16,000	20	0.30	3	Dwyer
2245	2	start descent	19	0.30	3	MSA
2254	2	descent	19	0.30	3	MSA
2300	2	descent & landing	19	0.15	3	MSA
2305	2	Taxi	19	0.20	3	MSA

B. FLIGHT TEST #2

Seaboard World Airlines CL-44

Approximately 200 pounds of dry ice was on board.

Position 1 - Behind pilot seat
Position 2 - 4 feet to 6 feet rear of cockpit door
Position 3 - 4 feet to 5 feet rear of position 2 (where cargo and seats are separated by canvas partition).

Cardboard food box with about 25 pounds of dry ice was occasionally opened to remove food. Box was in vicinity of positions 2 and 3.

TABLE II

FLIGHT TEST NO. II

TIME	POSITION	ALTITUDE	T°F	CO_2 CONC%	SAMPLE HEIGHT(ft)	TYPE SAMPLER
1700	2	engine start & taxi	68	0.03	3	MSA
1715	2	climb	62	0.11	3	MSA
1730	2	climb	62	0.02	3	MSA
1745	2	19,000	68	1.00	3	MSA
1800	3	19,000	68	0.20	2	Dwyer
1815	1	19,000	68	0.09	3	MSA
1830	2	19,000	66	1.10	6	Dwyer
1845	3	19,000	68	0.40	2	Dwyer
1900	1	19,000	68	0.30	3	Dwyer
1915	2	19,000	66	1.10	3	Dwyer
1920	2	19,000	66	1.30	6	Dwyer
1930	3	19,000	66	0.40	3	Dwyer
1945	1	19,000	68	0.30	3	Dwyer
2000	2	19,000	65	1.00	3	Dwyer
2015	3	19,000	66	0.30	2	Dwyer
2030	1	19,000	68	0.08	3	MSA
2045	2	19,000	64	0.10	3	MSA
2100	3	19,000	64	0.30	2	Dwyer
2115	1	19,000	64	0.60	3	Dwyer
2130	2	19,000	64	0.07	3	MSA
2145	3	19,000	64	0.30	2	Dwyer
2200	1	19,000	64	0.30	3	Dwyer

TABLE II (Cont.)

FLIGHT TEST NO. II

TIME	POSITION	ALTITUDE	T°F	CO_2 CONC%	SAMPLE HEIGHT(ft)	TYPE SAMPLE
2215	2	19,000	64	0.30	3	Dwyer
2230	3	19,000	64	0.50	2	Dwyer
2245	1	19,000	66	0.08	3	MSA
2300	2	19,000	66	0.70	3	Dwyer
2315	3	19,000	66	0.30	2	Dwyer
2330	1	19,000	66	0.50	3	Dwyer
2345	2	19,000	61	0.60	3	Dwyer
2400	3	19,000	61	0.30	2	Dwyer
0015	1	19,000	61	0.04	3	MSA
0030	2	19,000	61	0.70	3	Dwyer
0045	3	19,000	61	0.30	2	Dwyer
1100	1	19,000	61	0.07	3	MSA
0115	2	19,000	68	0.03	3	MSA
0130	2	start descent	68	0.03	3	MSA
0140	2	descent	68	0.01	3	MSA
0145	2	land	68	0.03	3	MSA
0255	2	take off	66	0.01	3	MSA
0310	2	climb	66	0.10	3	MSA
0330	2	climb	66	0.01	3	MSA
0345	2	22,000	68	0.05	3	MSA
0400	2	22,000	68	0.05	3	MSA
0415	2	22,000	68	0.06	3	MSA

TABLE II (cont.)

FLIGHT TEST NO. II

TIME	POSITION	ALTITUDE	T°F	CO_2 CONC%	SAMPLE HEIGHT(ft)	TYPE SAMPLER
0430	1	22,000	68	0.05	3	MSA
0445	2	22,000	68	0.05	3	MSA
0500	1	22,000	68	0.05	3	MSA
0515	2	22,000	68	0.05	3	MSA
0948	2	24,000	68	0.10	3	MSA
1000	2	24,000	68	0.10	3	MSA
1015	1	24,000	68	0.07	3	MSA
1030	2	24,000	68	0.05	3	MSA
1045	1	24,000	68	0.06	3	MSA
1100	2	24,000	68	0.08	3	MSA
1115	1	24,000	68	0.06	3	MSA
1130	2	start descent	68	0.07	3	MSA
1145	2	descent	68	0.08	3	MSA
1200	2	descent & land		0.07	3	MSA

C. FLIGHT TEST #3

On 6 September 1964, 16 barrels, approximately 1,490 pounds of dry ice was on board a C 135 leaving from Travis AFB and bound for Hickam AFB.

Dry ice was at positions 710 to 780 and loaded a6 0215 hours.

TABLE III

FLIGHT TEST # 3

TIME	POSITION	ALTITUDE	T°F	CO_2 CONC%	SAMPLE HEIGHT(ft)	TYPE SAMPLER
0230	780	on ground	52	0.09	5	MSA
0237	900	on ground	56	0.08	3	MSA
0245	1220	on ground	56	0.15	3	MSA
0300	650	on ground	56	0.05	3	MSA
0315	1220	engine start	56	0.85	3	MSA
0320	1220	Taxi	56	1.10	3	Dwyer
0324	1220	take off & climb	66	0.35	3	MSA
0335	1220	climb	70	0.18	3	MSA
0348	1020	cabin 5,000 35,000	74	0.16	3	MSA
0400	860	35,000	70	0.25	3	MSA
0415	710	35,000	70	0.30	3	MSA
0430	580	35,000	70	0.20	3	MSA
0450	460	35,000	68	0.10	3	MSA
0515	1220	35,000	70	0.09	3	Dwyer
0535	1020	35,000	70	0.06	3	Dwyer
0600	580	35,000	70	0.20	3	MSA
0615	cockpit	35,000	70	0.04	3	Dwyer
0630	860	35,000	70	0.04	3	Dwyer
0700	1220	35,000	70	0.05	3	MSA
0810		start descent	70	0.05	3	MSA
0815		start descent	72	0.08	3	MSA

TABLE III

FLIGHT TEST #3

TIME	POSITION	ALTITUDE	T°F	CO_2 CONC%	SAMPLE HEIGHT(ft)	TYPE SAMPL
0820		Start descent	72	0.10	3	MSA
0825		same	74	0.10	3	MSA
0830		& Touchdown	78	0.12	3	MSA
0837		Taxi	78	0.18	3	MSA
0920	1020	On ground	74	0.09	3	Dwyer
1010	1020	0	74	0.10	3	Dwyer
1015	1220	0	74	0.09	3	Dwyer
1020	860	0	74	0.07	3	Dwyer
1022	760	0	74	0.06	3	Dwyer
1025	650	0	74	0.04	3	Dwyer
1028	1080	0	74	0.04	3	Dwyer
1040	1220	Eng St	74	1.00	3	MSA
1045	1220	On ground stationary	74	1.10	3	Dwyer
1050	1220	Taxi	74	1.10	3	Dwyer
1055	1220	Taxi	74	1.00	3	MSA
1103	1220	Takeoff	78	0.20	3	MSA
1112	1220	Climbing	74	0.15	3	MSA
1127	1020	31,000	60-80	0.20	3	MSA
1135	860	31,000	72	0.07	3	Dwyer
1235	1020	31,000	76	0.04	3	Dwyer
1230	620	31,000	76	0.06	3	Dwyer
12	Cockpit	31,000	76	0.04	3	Dwyer

TABLE III

FLIGHT TEST #3

TIME	POSITION	ALTITUDE	T°F	CO_2 CONC%	SAMPLE HEIGHT (ft)	TYPE SAMPLER
1230	1220	31,000	76	0.07	3	MSA
1300	1020	31,000	76	0.03	3	Dwyer
1305	760	31,000	76	0.03	3	Dwyer
1310	620	31,000	76	0.03	3	Dwyer
1313	480	31,000	76	0.01	3	Dwyer
1345	1220	31,000	78	0.07	3	MSA
1350	930	31,000	78	0.17	3	MSA
1357	480	31,000	78	0.07	3	MSA
1425	1020	31,000	80	0.04	3	Dwyer
1500	860	31,000	80	0.03	3	Dwyer
1505	580	31,000	78	0.03	3	Dwyer
1508	Cockpit	31,000	78	0.02	3	Dwyer
1530	1020	31,000	78	0.12	3	MSA
1543	1220	31,000	78	0.07	3	MSA
1405	750	31,000	78	0.05	3	Dwyer
1415	650	31,000	78	0.03	3	Dwyer
1635	1050	31,000	80	0.03	3	MSA
1705	420	31,000	78	0.04	3	MSA
1710	710	31,000	78	0.25	6	MSA
1730	1220	31,000	78	0.05	3	MSA
1740	1220	31,000		0.10	6	MSA
1800	480	31,000		0.05	3	MSA

TABLE III

FLIGHT TEST #3

TIME	POSITION	ALTITUDE	T°F	CO_2 CONC%	SAMPLE HEIGHT (ft)	TYPE SAMPL
1835	Cockpit	31,000	78	0.05	3	MSA
1850	Cockpit	31,000	78	0.01	5	MSA
1850	620	31,000	78	0.10	3	MSA
1915	1220	31,000	78	0.10	3	MSA
1935	Cockpit	starting descent	78	0.07	3	MSA
1940	Cockpit	starting descent	78	0.10	3	MSA
1945	Cockpit	starting descent	78	0.10	3	MSA
1950	Cockpit	starting descent	78	0.05	3	MSA
1955	Cockpit	on ground	78	0.10	3	MSA

D. FLIGHT TEST #4

On 4-5 July 1964, a C 130 flight was made with 7 barrels, approximately 945 pounds dry ice on board from Travis AFB to Hickam AFB.

5 barrels were located between positions 730 and 820
2 barrels were located between positions 270 and 300

TABLE IV

FLIGHT TEST #4

TIME	STATION	SAMPLE HEIGHT (feet)	ALTITUDE	CO_2 CONC	T°F
0955	300	3	On ground finishing loading. Ramp just closed.	0.1	60
1020	440	3	On ground Engine start	0.2	60
1030	460	3	Taxi	0.25	64
1040	440	3	Takeoff	0.1	72
1045	720	3	3-4,000 feet climbing	0.5	74
1055	700	3	15,000 feet	0.2	74
1112	730	3	19-20,000 feet	0.25	76
1130	440	3	" " "	0.25	76
1145	270	3	20,000	0.15	64
1200	720	5	20,000	0.15	64
1215	Cabin	3	20,000	0.01	68
1230	440	5	20,000	0.1	74
1245	320	3	20,000	0.1	77
1300	700	5	20,000	0.15	64
1315	230	5 feet above floor at cabin entrance	20,000	0.07	74
1345	450	3	20,000	0.15	60
1400	750	3	20,000	0.15	59
1415	720	5	22,000	0.15	58
1430	720	5	22,000	0.02	58

TABLE IV (cont'd)

FLIGHT TEST # 4

TIME	STATION	SAMPLE HEIGHT feet	ALTITUDE	CO_2 CONC	T°F
1445	440	3	22,000	0.05	72
1500	290	3	22,000	0.05	78
1515	In cabin rear	3	22,000	0.05	76
1530	Back of pilot chair at head	4	22,000	0.06-7	76
1545	280	3	24,000	0.1	80
1600	450	3	24,000	0.2	68
1615	660	3	24,000	0.25	51
1621	660	5	24,000	0.12	50
1630	740	3	24,000	0.1	52
1637	720	5	24,000	0.1	50
1645	740	5	24,000	0.1	51
1652	Entrance to cabin	3	24,000	0.7	70
1700	Rear of cabin	3	24,000	0.7	74
1708	Behind head of pilot	4	24,000	0.7	74
1715	280	3	24,000	0.1	76
1722	390	3	24,000	0.18	60
1730	440	3	24,000	0.2	58
1737	560	3	24,000	0.1	68
1745	640	3	24,000	0.02	50
1752	690	3	24,000	0.02	48

TABLE IV (cont'd)

FLIGHT TEST # 4

TIME	STATION	SAMPLE HEIGHT feet	ALTITUDE	CO_2 CONC	T°F
1800	730	3	24,000	0.02	54
1813	440	3	Starting Descent	0.05	60
1821	440	3	Faster Descending	0.02	60
1829	440	3	Wheels down Descending	0.25	70
1834	440	3	Touch down	0.1	70

E. FLIGHT TEST # 5

On 5 July 1964, 4 barrels, approximately 540 pounds of dry ice, were loaded between 0730 and 0850 and bound for Wake Island from Hickam AFB.

TABLE V

FLIGHT TEST #5

TIME	STATION	SAMPLE HEIGHT (feet)	ALTITUDE	CO_2 CONC	T°F
0621	450	3	Taxi	0.12	80
0638	450	3	Takeoff	0.1	80
0743	730	3	4,000	0.25	80
0753	730	3	15,000	0.12	70
0938	390	3	20,000	0.05	72
1026	Back of pilot head	4	20,000	0.1	72
1036	700	3	20,000	0.25	60
1140	450	3	22,000	0.25	61
1200	730	3	22,000	0.15	54
1205	Entrance to cabin	3	22,000	0.06	68
1300	710	3	24,000	0.25	58
1330	380	3	24,000	0.15	60
1336	Entrance to cabin	3	Starting descent 24,000	0.1	70
1348	400	3	Touchdown and taxi	0.05	70

APPENDIX V

DRY ICE SUBLIMATION FROM INSULATED CARTONS OF DRY ICE COVERED BY BLANKETS LABORATORY TESTS 1-4

A. LABORATORY TEST NO. 1. 2.18 cubic feet carton with inner insulated carton, McClellan AFB, California, 2 March 1964. Carton Data:

1. Outer Carton: 18 x 15 1/2 x 13 1/2 inches, cardboard. T.O. Spec. PPP-B-636b.

2. Inner Carton: 13 1/2 x 12 1/2 x 9 inches, cardboard. Insulated between two cartons with expanded rock-wool type insulation and inner box padded with 1 inch layer of hog hair mat.

3. Sublimation Rate: $\frac{22 - 10}{16/100 \quad 24.8}$ = 3.23 lbs/100 lbs/hr

B. LABORATORY TEST NO. 2 - TRAVIS AFB, CALIFORNIA, 15 APRIL 1964.

1. Dry Ice Data: 584 pounds of dry ice in 50 pound brown paper wrapped packages were wrapped in seven G.I. wool blankets and placed on a pallet. This made a package 24 inches high and 2 1/2 feet x 2 feet at base.

Gross weight at 1030 hours	672 lbs
Blankets and pallet	88 lbs
Net weight	584 lbs

2. Effect of Movement: After weighing, the pallet load was carried by a fork lift one half of the way to the aircraft pit and back to measure effect of carrying from scales.

Gross weight at 1045 hours	665 lbs
Loss in transport	7 lbs

After last weighing, the pallet load was again carried by fork lift one half of the way to the aircraft and back.

Gross weight before movement (1345 hrs)	645 lbs
Gross weight after movement (1400 hrs)	640 lbs
Loss in transport	5 lbs

3. Sublimation Rates:

Normal $\dfrac{577 - 555}{566/100 \quad 2.75}$ = 1.41 lbs/100 lbs/hr

Initial transport $\dfrac{584-577}{\frac{580.5}{100} \quad .25}$ = 4.82 lbs/100 lbs/hr

Final transport $\dfrac{555 - 550}{552.5/100 \quad .25}$ = 3.62 lbs/100 lbs/hr

TABLE I

LABORATORY TEST NO. 1
SUBLIMATION RATE OF DRY ICE IN INSULATED SHIPPING BOX
USED AT McCLELLAN AFB, CALIFORNIA
2 March 1964

Weight Data
Weight of box = 18 lbs
Initial dry ice = 22 lbs
40 lbs

Δ t Hours	Gross Wt Lbs	Dry Ice Lbs	Loss Lbs	Ambient Temperature
0.00	40	22	--	75.5°F d.b.. 59.0° w.b.
0.17	39.75	21.35	0.25	
0.47	39.50	21.50	0.50	
0.92	39.25	21.25	0.75	
1.50	39.25	21.25	0.75	
2.17	38.50	20.50	1.50	75.5°F d.b.
3.00	38.12	20.12	1.88	
17.75	31	13	9	
23.58	28.50	10.50	11.50	
24.75	27.75	9.75	12.25	77°F d.b., 58° w.b.
25.58	27.50	9.50	12.50	
42.83	20.50	2.50	19.50	
45.42	19.75	1.75	20.25	
48.17	19	1	21	
50.17	18.50	0.50	21.50	
67.17	18	0.00	22	

t = expired time

TABLE II

LABORATORY TEST NO. 2
DRY ICE SUBLIMATION RATE

Time	Gross Weight (lbs)	Tare Weight (lbs)	Net Weight (lbs)
1030	672	88	584 Transported
1045	665	88	577
1100	662	89	573
1145	660	90	570
1255	650	90	560
1347	645	90	555 Transported
1400	640	90	550

C. LABORATORY TESTS NO. 3A and 3B - McClellan AFB, California 28 April 1964

1. Dry Ice Data: 545 pounds of dry ice in 12 brown paper wrapped packages were placed in a stack, nine in first row and three in second row wrapped tightly with six G.I. wool blankets, and placed on a platform scale.

2. Weight Data:

Weight of blankets	21.5
Gross weight of load at 0925 hours	558.5 lbs. still air test
Gross weight of load at 1509 hours	528 lbs. moving air test
Final weight of blankets	25.5 lbs.

3. Sublimation Rates:

Still Air $\quad \dfrac{537-500}{\dfrac{518.5}{100}} = \dfrac{6.5}{5.185} = 1.09$ lbs./100lbs.hr.

9.1 M.P.H. Wind $\quad \dfrac{504.5-480}{\dfrac{492.3}{100}} = \dfrac{4}{4.923} = 1.24$ lbs./100lbs.hr.

TABLE III

LABORATORY TEST NO. 3 A
STILL AIR

Tare Weight 21.5 Temp. (1935) = 77° db, 62.5 w.b.

Time	Expired Time		Gross Weight (lbs)	Dry Ice Weight (lbs)
	Min.	Hr.		
0925	--	--	558.5	537
0933	8	.13	557.5	536
0941	16	.27	556	534.5
0947	22	.37	556	534.5
1006	41	.68	554	532.5
1032	67	1.12	551.5	530
1050	85	1.42	549.5	528
1140	135	2.25	545.5	524
1248	203	3.38	540	518.5
1324	239	3.98	537	515.5
1400	275	4.58	534	512.5
1438	313	5.22	530.5	507
1500	335	5.58	529.5	508
1555	390	6.50	521.5	500

TABLE IV

LABORATORY TEST NO. 3 B
MOVING AIR
800 Linear Feet Per Minute
(9.1 mph)

Tare 122 lbs
25.5 lbs next day
Use 23.5

783 mm Hg @ 74°
74° dry bulb, 65° wet bulb

Time	Expired Time		Gross Weight (lbs.)	Net Dry Ice Weight (lbs.)
	Min	Hrs		
1509	--	--	528	504.5
1525	16	0.27	526	502.5
1551	42	0.70	523.5	500
1612	63	1.05	521	497.5
1630	81	1.35	519.5	496
1638	99	1.65	518.5	495
1708	119	1.98	517	493.5
1732	143	2.38	514.5	491
1741	152	2.53	514	490.5
1759	170	2.83	512.5	489
1820	191	3.18	510.5	487
1909	240	4.00	493.5	480

D. LABORATORY TEST NO. 4

1. A large standard insulated food container was used in this test with a tare weight of 52.5 pounds.

2. Sublimation Rate: $\frac{30 - 14}{22/100 \times 22.8} = 3.02$ lbs/100 lbs/hr

[redacted]

TABLE V

LABORATORY TEST NO. 4
DRY ICE DATA
FOOD CONTAINER

Time	Expired Time (hrs)	Gross Weight (lbs)	Net Weight (lbs)
0842	--	82.5	30
0848	0.10	82.5	30
0905	0.38	82	29.5
0922	0.67	81.5	29
0948	1.10	81	28.5
1025	1.71	80.5	28
1218	3.60	79	26.5
1323	4.68	78.5	26
1353	5.18	78	25.5
1505	6.39	77	24.5
1545	7.05	76.5	24
1613	7.51	76	23.5
1638	7.95	76	23.5
1725	8.72	75.5	23
0730	22.80	66.5	14
0820	23.63	66	13.5
0847	24.08	65.5	13
0915	24.55	65.5	13

TABLE V (CONT'D)

LABORATORY TEST NO. 4
DRY ICE DATA
FOOD CONTAINER

Time	Expired Time (hrs)	Gross Weight (lbs)	Net Weight (lbs)
1958	25.27	65.	12.5
1040	26.00	64.5	12
1104	26.37	64	11.5
1125	26.71	64	11.5
1234	27.87	63.5	11
1350	29.13	62.5	10
1445	30.05	62	9.5
1530		61.5	9.0
1610		61.3	8.8
1637		61	8.[illegible]
0715		55	
0900		54	
0930		54	
0953		53.75	
1100		53.75	